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Improving Mobile Networks based on Social Mobility Modeling

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Improving Mobile Networks based on Social Mobility Modeling

Thesis Progress Report, Doctoral Programme MAP-TELE Edition 2011/2012

Andréa Guimarães Ribeiro (University of Aveiro/SITI, University Lusofona)

July, 2012

Advisors: Prof. Rute Sofia (SITI, University Lusofona), Prof. André Zúquete (University of Aveiro/IT/IEETA)

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Abstract

This report corresponds to the second progress report related to the thesis work entitled "Improving Mobile Networks based on Social Mobility Modeling", MAP-TELE edition 2009/2010. The activities here reported and the work achieved comprise the period between July 2011 and June 2012, period which corresponds to the second year of the thesis development [22].

The proposed thesis has as main goal to analyze how, by capturing properties of devices in motion in realistic environments, mobility modeling can assist different aspects of wireless network operation e.g. handover optimization; resource management; routing; and even a better autonomic deployment of connectivity models mainly due to the possibility of more adequately predicting node's future placement.

The work proposed is focused on the analysis of current social mobility models and how to propose a new model having in mind an overall network optimization due to the possibility to predict adequately node's movement on mobile networks. The report describes some specific related work considered for the activity and also explains in details what have been done and the main parameters identified to define a realistic human mobility behavior. Based on these parameters, the report also shows the pause time proposal considering social aspects, a proposal used to define nodes trajectory changes on motion, and a first draft of a conceptual framework to develop a social mobility model.

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Chapter 1

Introduction

Short-range wireless devices, such as *Wireless Fidelity (Wi-Fi)* devices, are in their majority carried or controlled by humans thus exhibiting movement patterns that are related to human mobility behavior. Such movement patterns impact the received signal strength and hence it impacts connectivity models, routing performance, and resource management. In other words: movement of mobile nodes impacts the network operation overall. Ideally, if one can infer mobility characteristics based upon human behavior then one may or may not be able to predict some aspects related to the network operation (e.g., handover). Predicting such movement implies having an adequate perception on statistical properties of mobility, i.e., being able to adequately *model* mobility.

In order to model realistic social movement, we need to understand the needs of humans, but also understand how to relate these needs in space and time. A realistic mobility model should be able to model human routines, as every morning go to office or gym; however, as mentioned previously, humans can decide what to do at any time, then, imagining that along his/her path to the coffee-shop the end-user meets a friend and decides to change its route, opting to visit a new coffee-shop. Hence, a realistic mobility model also should be able to model this behavior (change on the fly), considering in this case, the interest of this user to its friend (maybe this user has a higher attractiveness with its friend than with the coffee-shop).

The thesis propose to develop work related to the analysis and realistic application on social mobility modeling as a relevant tool to optimize network operation. Expected contributions out of this work relate to novel mechanisms capable of estimating social mobility based on a human behavior.

This report comprises work developed between July 2011 and June 2012, thus corresponding to the second year of thesis after the proposal. The report is organized as follows. Still in this section we position the work developed in terms of goals to be achieved, and of active tasks. Chapter 2 relates additional work that we have analyzed during the period being reported. Chapter 3 provides an overview of different aspects that we have analyzed to better define the human movement. Chapter 4 shows our pause time proposal, considering social aspects and also our first proposal to define nodes trajectory changes on motion. Chapter 5 is dedicated to show our summary and achievement, and finally Chapter 6 provides the description for the future work.

1.1 Goals and Roadmap

Often and in terms of network self-organization, mobility is treated as a secondary aspect. In user-centric environments, mobility is a key feature given that *roaming* is one of the main properties of such environments. Being able to track mobility and to learn about how such tracking can be performed in an autonomic way can assist in estimating the network behavior. Hence, main goals proposed for this thesis were:

- **To analyze recent state-of-the-art concerning mobility modeling and its application in wireless networks**. A specific study about the existing solutions related to mobility pattern tracking, showing the advantages and disadvantages of each model, is to be delivered. Such analysis (which will include but not be limited to the references provided in this document) will help to better understand the problem space to be addressed, namely user-centric wireless environments. The analysis will contemplate not only novel concepts being addressed, but also available tools (e.g. traces, emulators, test beds) that will be useful throughout the development and validation of concepts.
- **To conceive, validate novel models and functions**. This goal will consider available tools (models, traces) and the addition of new parameters, which will be built upon the most recent mobility models to evaluation these models.
- **To contribute with an analysis on how mobility modeling assists the network operation**. This analysis will follow a top-bottom approach, by first looking generically into the network operation and its most relevant aspects, to then become more focused in specific aspects such as resource management.
- **To contribute with a novel social mobility model that can be applied in reality**. Such mobility model will be developed by taking into consideration realistic aspects of human mobility patterns, as well as features from the networking layers. It will also consider current models developed and if adequate, be based on a specific model. But the key aspects to consider relate to a design that will include how such model can be incorporated into real-life scenarios, to assist in adequately estimating node movement.

To tackle the mentioned goals the thesis workplan considers the following roadmap:

- **Activity 1: Brainstorming phase (July 2010 - July 2011)**
  - Expected outcome: intermediate progress report; 1 magazine/journal publication; 1 poster publication; 1 international conference/workshop publication.
- **Activity 2: Specification/validation phase 1 (July 2011 - June - 2012)**
  - Expected outcome: intermediate report; novel algorithms and/or mechanisms specified (main aspects) and validated (simulations); 1 poster publication; 1 conference publication.
- **Activity 3: Specification/validation phase 2 (June 2012 - December 2012)**
  - Expected outcome: intermediate progress report; novel algorithms and/or mechanisms and/or updates specified and validated (simulations or test beds); 1 international conference publication; 1 journal publication.

- **Activity 4: Consolidation/Thesis Wrap-up phase (January 2013 - June 2013)**
  - Expected outcome: final thesis; 1 international conference publication; 1 journal publication.

1.2 Work Covered in this Report

The work developed in this activity year corresponds to the Activities 2 and 3, according the thesis workplan.

During this year, we had improved the pause function, considering mainly the analysis made by the reviewers from the previous conferences that we had submitted papers, according is showed in subsection 4.1 from this report, where the first draft of the algorithm is available in [21].

Another aspect that has been solved, however, we are still working on it; is the possibility to change the trajectory during nodes' movement, which is presented on subsection 4.2.

During the period being reported, we also have worked on the following aspects:

- Analysis of various parameters to define the modeling of motion-based social aspects.
- The creation of a new conceptual framework, that will assist a developer to create a realistic social mobility model.

Chapter 2

Related Work

A number of approaches have been dealing with trying to detect node mobility and also trying to quantify up to some extent human movement behavior. This is expected to assist in a better definition of several aspects of network operation, given that today most of the available mobile devices are carried or owned by humans. Such attempts fall under the category known in related literature as *social mobility modeling*.

In this section, we present the latest advances concerning social mobility models. Given that, in our last report we presented the most common social mobility models [22, 23], here, we will show the most common related work about framework of social mobility model.

Karamshuk, et al. [10] built a framework, where is possible extract some important information (e.g. inter-contact time and contact duration) from any type of scenarios, to use in One simulator [11]. The inter-contact time and contact duration are important features for opportunistic networks, where the time interval between two consecutive contact between two users (inter-contact time), can express the expected delay of message could diverge; and the contact duration between two users can express the length of a message that these users can exchange. The authors also provided a very interesting work, where they show some statistic properties of human mobility, divided into three axes; spatial, temporal and connectivity [9]. This work is more related with how we should evaluate a new social mobility model. The authors show, for instance, that travel distances (*jump size*) should follow a power-law distribution, as well as the time interval that a user spends in a specific place (*pause time*), follow a truncated power-law. Hence, a realistic social mobility model, should have results for pause time, with the same behavior of a truncated power-law. However, how we should specify how long a user will stay in a place, this value is related with the place, or with the people that visit that place? Unfortunately, we do not have a work that describe the necessary features to calculate the main properties of human mobility.

The framework proposed by Mousavi et al. [15], called MobiSim, is a very interesting tool for the simulation of mobility models in Mobile Ad Hoc NETworks (MANETs). However, the authors do not define how/what, a new user should do to develop a new social mobility model, we believe that MobiSim is more related with a tool used to generate mobility traces based on some existing mobility models (e.g. Random Waypoint, Manhattan, Random Walk). Another tool, which also generates mobility scenarios based on the most recent mobility models (e.g. SLAW, RPGM, etc.), is the BonMotion [4], which in this case, can export mobility traces for some network simulators, such as; ns-2, ns-3, ONE, among others.

A framework based on the fuzzy set theory proposed by [12], is a framework to evaluate mobility models based on their mobility characteristics. The authors consider that the mobility models can be split in five main groups, considering random features, social behavior, among others. And, based on these features, the framework can specify to what degree the real world mobility trace belongs to each mobility classes or mobility models. However, again we have a framework that is used to evaluate and not to show how it is possible to develop a social mobility model.

Another set of work that we have analyzed in this activity year, are the work about the necessary parameters to implement in the social mobility model, such as: cluster algorithms (community detection), how to provide routine in a social mobility model, distance, etc.

The Caveman algorithm was proposed by Watts Watts (1999) [28], where initially a social network starts with all its edges (nodes) fully connected. In a second moment, every edges of this social network is re-wired to a node of another social network with a certain probability p. This process is used to establish interconnection between communities of social networks. Another cluster algorithm that we also analyzed was the Girvan-Newman [18], where differently from the others cluster algorithms, this algorithm does not construct communities. The communities are detected by removing edges from the original graph of the network. The edges are removed considering the highest betweenness; in other words, the algorithm removes the edges of the nodes that has the highest centrality, based on the shortest path between all pairs of vertices that run along it. The *k-clique* algorithm proposed by Palla et al. [19] is other known cluster algorithm used to communities detection in social networks. The *k-clique* community is the union of all k-cliques which can be reached from others adjacent *k-cliques* (i.e. they share $k-1$ nodes).

Another important aspect analyzed was the distance, given that humans prefer short to long distances [3]. And moreover, human trajectories are characterized by fat-tailed distributions of jump sizes and waiting times [26].

Chapter 3

Mobility Modeling Aspects

During the last year and as part of Activities 2 and 3, we have been working with how to best model mobility, and in particular, how to best model human mobility. For that, we have analyzed related work both from a conceptual and implementation perspective. Then, we have considered aspects that are crucial, derived from traces and also from models that have been proposed in the period being reported. The chapter addresses parameters that we are considering in our work, as parameters required in the modeling of human movement.

3.1 Parameters Analyzed in the Previous Period

- Pause time - it was the first analyzed parameter, where we have implemented a new pause time function considering the relationship between pauses and the social interests among nodes.
- Free Will Impact on Movement - it was the second analyzed parameter; and we believe that the appropriate name to this feature is trajectory changes; where we are implementing this feature especially considering changes in destination locations.

3.2 Parameters Analyzed During the Reported Period

3.2.1 Social Attractiveness

As showed in the previous section some human behavior modeling, here we will emphasize and explain a function that considers the notion of *social attractiveness,* which is today starting to be used to model node movement as close as possible to the human roaming behavior. Human movement is strongly affected by the needs of humans to socialize or cooperate, in one form or another.

In social mobility modeling, the line of thought currently being followed (based on empirical findings from social sciences) is: humans organize themselves into groups which only have a meaning at some instant in time and in space. These groups, known as communities, have a spatial and temporal correlation. Examples of communities are: affiliation; family; club. The community formation block is necessary to define the relationship among nodes in the social mobility model. Most of social mobility models use a cluster algorithm to specify this relationship forming groups/communities that may vary in time. We will show the most common cluster algorithms that can be incorporate in a social mobility model, however, we want to make clear, that we believe it is not necessary to use an specific cluster algorithm to split nodes in communities for a social mobility model. When a social graph is defined, automatically the links (values in the range [0,1]; being "0" a weak social affinity and "1" a high social affinity) represent the social relationship between nodes, forming communities at a specific instant in time and in space, i.e. when a node meets another node at a given instant in time, they form a community.

3.2.2 Proximity

Proximity is an important feature that should be considered in predicting the nodes movement in a social mobility model, given that humans prefer short to long distances [3], hence in a realistic mobility model it is a feature that should take into consideration in the movement function. SLAW [13] uses the distance to define the order of waypoints will be visited; and SIMPS [2] uses the *power of the distance* parameter to specify the movement vector size. We believe that the proximity associated with the social attractiveness among nodes is a great influence on the decision to move.

3.2.3 Routine

In this subsection we provide a few notions for the sake of clarity, and discuss also some aspects related to how consider the routine in social mobility models. Routine can be defined as the regular patterns, where the same places are visited every day; such as going to an office [13]; or the simple fact that a day can be divided in morning, afternoon and night (i.e. 8 hours), as is done by Musolesi in [17] with the *reconfiguration interval*.

From our perspective, the routine should be considered in a movement definition and it is more related with a time interval, and not a specific place. The fact that humans go every day to their office, we also can associate to the fact that, a person visits his/her coworkers (community) every day in a specific instant in time. The routine also can be variable, only in the morning and night (12 hours), and at the end of this period nodes back to initial position, or to their initial communities (e.g. at end of day, usually a person goes back to it's home with its family).

3.2.4 Collision Avoidance

Collision Avoidance is a known characteristic, however most of then does not consider this feature [20, 17, 2, 1]. Despite the fact that this feature is not related with a social aspect, we believe that to provide a realistic human behavior, we can not allow that nodes have the same position in a simulation scenario. Trying to be as simple as possible, we believe that the mechanism provided by [6] which keep a small distance between nodes, is a simple mechanism to avoid collision between two nodes.

3.2.5 Pause Time Aspects

The basic definition of pause time in related literature corresponds to the *time interval where a node is stationary*, i.e., its speed is zero. This definition does not apply completely to scenarios where networking nodes are carried by humans. In such cases, portable devices exhibit some form of individual movement and hence a second definition provided in related literature states that pause time corresponds to the time interval where a node has a speed "close" to zero, e.g., the node moves less than r meters in 30 seconds [20]. In this section we provide a few notions concerning social mobility modeling for the sake of clarity, and discuss also some aspects related to the modeling/tracking of pauses.

From our perspective, pause time is a product of *affinities* between nodes. In other words, similarly to what is proposed in social mobility models for the modeling of the movement dynamics [5], we believe that the modeling of pause time should take into consideration affinities between nodes.

One embodiment of node affinity is *social similarity* as previously defined by K. Jahanbakhsh, et al. in the specific context of opportunistic routing [7]. The authors define a node u to be more "socially similar" to node v than w, if u is more likely to contact v than w. We follow this line of thought for our work on pause time and formulate the following hypothesis: if node u is more socially similar to a node v than a node w, then if node u encounters v and w, it is expected to spend more time with node v than with w.

A measure of social attractiveness is therefore an adequate factor to consider as basis for a function capable of dynamically model a node's pauses, being the underlying assumption the fact that humans tend to pause more time closer to whom they exhibit stronger affinities.

3.2.6 Trajectory Changes

A crucial aspect related to human movement is the possibility to change the course of action at any instant in time. Free will/Freedom of action is a relevant social aspect and one which provides variability to movement modeling. Free will implies that humans may change direction abruptly; change their path or stop. This level of variability is not random; instead, it is tied to the sociological notion of interest. Humans change previous made decisions based on a change of interest at some instant in time and in space. Hence from a mobility modeling perspective it is relevant to be able to capture sudden changes, be it in direction, in speed, or even in pausing that a node should be able to change its direction during its movement if something happens (e.g. it receive a call, an accident happens). However, the current mobility models define the mobile nodes movement and only when the nodes reach in their destination a new goal is calculated. We provide more explanation on Section 4.2, given that, we do not know any social mobility model that consider this feature.

3.2.7 Speed/Acceleration, Adding Variability

To provide a realistic modeling for node movement patterns (assuming nodes are carried by humans), it is first necessary to define a few relevant parameters. For instance, a user carrying a node is walking at a constant speed; when realizing he is delayed to catch the bus, the user speeds up. As humans, our speed is not uniform. Most of the social mobility models [16, 5, 8, 13, 2] define the nodes speed uniformly between an interval, and constant during movement. S. Gunasekaran and N. Nagarajan, define group speed based on the inter relationship matrix (relation between nodes from the same community) and cumulative nodes speed [6]. Moreover, to provide collision avoidance between nodes in movement their model can track decelerations by providing a variable delta in distance between a node and its neighbors.

Another model that does not consider the speed from an specific interval for all the nodes is SWIM [14], which as has been previously mentioned, defines node speed based on the distance from the destination. Albeit interesting this model still considers speed to be constant in each movement step of the simulation.

3.3 Summary

Analyzing all these parameters, we believe that each one have an important role in a global social mobility model.

The social attractiveness; the proximity; and the routine are directly related to the choice of the next target for an individual node. Hence, in our function to defined the next node's target (the next node's destination), all these parameters should take into consideration. For instance, it was proved that people organize their lives in communities and move between them; besides prefer short distances. Also considering their daily routine, visit the same places often. Hence, we believe that using a probabilistic function, we can define the next node's destination taking into consideration these main three parameters.

The others parameters, such as; collision avoidance, pause time, trajectory changes and speed/acceleration are related to the movement modeling, i.e. how the nodes will move to their target. Considering the collision avoidance, we are more interested in collision between nodes, i.e., two nodes can not are at the same place. We already defined pauses when a node reaches at its destination, however, we also should take into consideration pauses when a node meet a friend during its movement, and this must be related to their social relationship.

Considering the trajectory changes, as explained, nodes should be able to change its trajectory before to reach at its previous destination if necessary. And the last important parameter to consider on movement modeling is the speed/acceleration, where most of the existing models define a constant speed during all nodes movement, what is not realistic. Our proposal is that, the speed should vary according to the distance and social attractiveness.

3.4 Tools Analyzed

In this year, we are not using different tools from the previous report (e.g. CMM standalone simulation, ns2, crawdad, bonmotion). However, we are developing a new social mobility model, hence, CMM standalone simulator, will be used just for comparison. We are also using in this year R-language [27], which is a language and environment for statistical computing and graphics, which we are using to do analysis in traces and to do some results comparison.

Chapter 4

Results Achieved in the Current Period

4.1 Improving Our Pause Time Proposal

Pause time is here strictly connoted to the time interval that a mobile node is steady in a specific position, i.e., the interval of time when the node's speed is zero or, as in some previous studies [20], where the user's speed is close to zero. The dynamics of pause time modeling integrates two different scales: a node exhibits an individual type of movement even when not in motion towards a target. That movement is confined to a personal space (e.g. a PDA on the pocket of its owner). Pause time can also be perceived from the perspective of a node towards its neighboring nodes. For instance, if nodes are moving in group but keeping a relative and constant speed and direction, then a node, from the perspective of its neighbors, seems to be stationary.

From our perspective pause time is a product of *affinities* between nodes, i.e., a result of their human carriers sharing some form of interest. In other words, similarly to what is proposed in social mobility models such as CMM for the modeling of the movement dynamics, we believe that the modeling of pause time should take into consideration affinities between nodes. Such affinities can be measured by providing a cost of the *social strength* between two nodes. *Node affinity* or *social strength* is the cost of an association between two nodes and related to potential shared interests. Node affinity therefore implies a spatial-temporal correlation.

To better provide an understanding of these notions let us further explain what happens when humans roam. Persons move towards specific nodes or locations based on specific interests e.g. affiliation, leisure. During such movement, persons may move in group intentionally or not. For instance, when riding the same bus, strangers will, from a network perspective, exhibit a similar movement pattern.

Our proposal for tracking the dynamics of pause time on social mobility models is a reflection of the following line of thought: if a node has a higher social attractiveness for a specific target, then it normally spends more time on the selected target. The reasoning behind this line of thought relates to the notion of shared interests by nodes which result in a time and space correlation.

To better illustrate our line of thought we recur to Table 4.1 for summarizing the notation used in this section, and to Figure 4.1 to provide a concrete example. The node represented in black stands for the node we are observing, node i. Grey nodes correspond to nodes j which exhibit a strong social attractiveness (high social attractiveness, $w_{i,j}$ towards node i); white nodes correspond to regular nodes j with a normal social attractiveness weight towards node i.

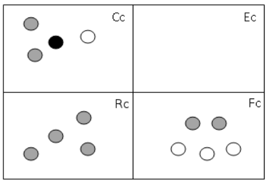

Figure 4.1: Example of node clustering with different SAs.

We model pauses based on function $P(i)$ provided by Equation 4.1. We assume that there is a direct relation between pause time and social attractiveness, and on this work, for the sake of experimentation, we consider such relation to vary linearly.

Table 4.1: Notation used in pause time function.

a	Minimum pause time
$SA_{C_{p,q}}$	Social Attractiveness for Cluster p,q
n	Number of node in a cluster
d	Maximum pause time
$w_{i,j}$	Social attractiveness weight from node j towards node i
$w_{i,j_{max}}$	Maximum attractiveness weight on a cluster
$w_{i,j_{min}}$	Minimum attractiveness weight on a cluster
α	Threshold for the social attractiveness level

$$P(i)_{C_{p,q}} = a + (SA * (d - a) * f_{C_{p,q}}) \tag{4.1}$$

$$f_{C_{p,q}} = \begin{cases} \frac{|S|}{n}, & |S| > 0 \\ w_{i,j_{max}}, & |S| = 0 \end{cases}, \ S = \{w_{i,j} \geq \alpha,\ j \in C_{p,q}\}$$

$P(i)$ can be described as follows. The pause time of a node i in regards to a target cluster $C_{p,q}$ is modeled to be at least "a" seconds[1] and takes into consideration not only the cluster social attractiveness towards i but also the number (cardinality of set S) of nodes that contribute the most to such attractiveness, i.e., the number of nodes j that have a $w_{i,j}$ higher than α. Assuming that we have a cluster that holds no nodes under such conditions, i.e., all nodes j exhibit a $w_{i,j}$ lower than α, then we consider only the maximum value of $w_{i,j}$. The reasoning for this assumption relates to the fact that as node i will spend some time on cluster $C_{p,q}$ despite the fact that all nodes in this cluster seem to exert weak attractiveness to node i, then the time node i remains in

[1]In this work we consider the minimum and maximum pause time to be a constant value. In future work we intend to address as a function of other externalities, e.g., the frequency of roaming or the node speed, for instance.

that cluster should take into consideration the maximum strength exerted. We are conscious about the fact that this is a strong assumption which needs to be proven and in order to best assess the impact of this assumption, in the evaluation we will also consider the case where the pause time will take into consideration the lowest $w_{i,j}$ in the cluster.

We now describe the behavior of $P(i)$ based on the scenario (Figure 4.1). We start by the case where node i is moving towards a region where there is no cluster (and hence SA corresponds to 0), region which has been numbered as 2. $P(i)$ then becomes the minimum pause time, a.

Now, considering that the node i is moving towards a cluster composed of nodes that exhibit a low attractiveness towards node i, cell 3. Pause time is influenced by the duration of the routine, represented by the maximum pause time (d); by the social attractiveness (SA), and we also consider a concrete factor (maximum or minimum social attractiveness) to model pause time for this case. The last case is when the node i moves towards a region with a few nodes exhibit strong affinity, region 4; our function takes into consideration the number of nodes with a high social attractiveness as a factor that will increase the pause time.

For details about our pause time function results, a paper was published in [25], according summary af achievements in Section 5.

4.2 Analyzing the Impact of Human Spontaneity - Addressing Potential Trajectory Changes

A second aspect that we have been dealing with relates to providing social-based movement modeling functions with more variability during a specific course of action. This section describes a few initial ideas that can assist in modeling how a mobile node can change its direction during an already set movement towards a target, and mainly why it is an important feature to be considered in a realistic social mobility model.

A crucial aspect related to human movement is the way that humans socialize. Humans organizing themselves into *communities* and hence their movement is based upon the way these communities (e.g. friends, family, colleagues) are formed. Then, if a community moves to a new location during the nodes movement, it should change its direction before reaching in its destination. We use one example to illustrate the cause of human to change its direction during its movement. As shown in Figure 4.2, we have four mobile nodes A, B, C and D, where two of them (B and C) form a community (e.g. coworkers). Moreover, the Figure 4.2 also shows the nodes movement in different instants in time.

Let us consider that this scenario represents a realistic environment, where the nodes move towards other nodes or other communities based on their social relationship that may also change in time. Considering now

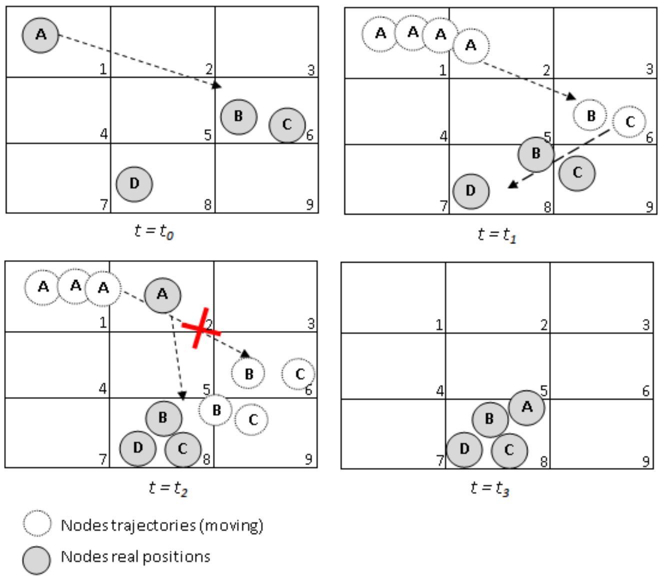

Figure 4.2: An example of node and community mobility.

the node A movement, its next destination will be the community formed by nodes B and C, as showed in time $t = t_0$. However, in time $t = t_1$ (during the movement of node A) the nodes B and C also starts to move for another place (in the direction of node D). Considering what happens in real life, node B or C would notify node A that they now go somewhere else (e.g. call phone), then in this time, node A will re-calculated its route to decide its new destination, which may or may not be the same destination of nodes B and C. In time $t = t_2$ we can see that the new destination of node A is the same place chosen by nodes B and C, where node D is. This happens because, despite of in real situations, humans can move to areas without people or for reasons not related to their social sphere, the probability of a node go to where its friends are, is higher. Then, in time $t = t_3$ the nodes reach their destinations, forming a big community.

To provide a dynamic way of splitting the time a node may take in its trajectory, we consider the euclidean distance between the node's origin and its chosen target, as well as the average speed s_i at which a node i is moving to compute the estimated trajectory duration L_i, as provided in Equation 4.2, where $\|x_i - y_i\|$ corresponds to the euclidean distance in meters between node i current position (x_i) and its computed target position (y_i). We consider an Exponential Moving Average (EMA) to keep track of the variability of L through time.

$$\frac{L_i = \|x_i - y_i\|}{s_i} \tag{4.2}$$

The mechanism works as follows. Once a node i starts its trajectory, it computes the target and the estimated trajectory duration, L_i considering node's speed (s_i) at that moment. Whenever the time-window (L_t) expire, the probabilistic social attractiveness function used to compute a new target is recalculated to check whether the target was a change (e.g. number of nodes at destination, social attractiveness). If everything have the same value or have higher value (i.e. number of nodes at destination or social attractiveness), then node i keeps moving to toward its target. However, if target's behavior was changed to lower values, which means that its friends may have left that community, a new target is computed, having three main possibilities for selecting a new target: The first one is the node i keeps moving to toward its previous target, for reason not related with its social relationship, however because that place; the second is the possibility of node i select the same destination that its friends, being this the highest probability mainly due to its social relationship; and the last possibility is the node i selects a completely different target.

As we rely on an EMA, L_t becomes more accurate with time. Depending upon the changes in trajectory and the node average speed, the next re-computation interval is computed.

The choice of the initial interval can of course be made less conservative. This is an aspect to be pursued in a future version of our work, by addressing regular time-window mechanisms, for the initial computation value, e.g. with regards to the node speed. Even though our mechanism allows trajectory changes to occur when a node is on the move.

4.3 Defining a Realistic Social Mobility Model - Decomposition

We did a functional analysis of the most popular social mobility models. Such analysis results in the functional deconstruction of each model into concrete blocks being the motivation to identify the most relevant pieces of each model, and gaps that are not yet filled in. We considered the following models: The Community-based Mobility Model (CMM)[16]; The Interaction based Mobility Model (SIMPS) [2]; and the Self-similar Least Action Walk (SLAW) [13].

For each model, we analyzed the different components they consider when modeling mobility patterns, namely: i) initial setup; ii) community modeling; iii) topology modeling; iv) target selection; v) movement modeling. Moreover, for each of these components, which we refer to as *functional blocks*, we also consider different parameters (e.g. speed, collision avoidance, pauses).

Figure 4.3 provides the first draft of the decomposition of a realistic social mobility model. The setup phase relates to the initial and one-time setup of configurable parameters required for a model to run. The community modeling block relates to social properties, i.e., grouping of nodes according to social properties (e.g. friendliness; attraction; affiliation). The third block, topology modeling, is related with the positioning of nodes and edges between nodes, as well as the modeling of variations over time and space. Target selection is

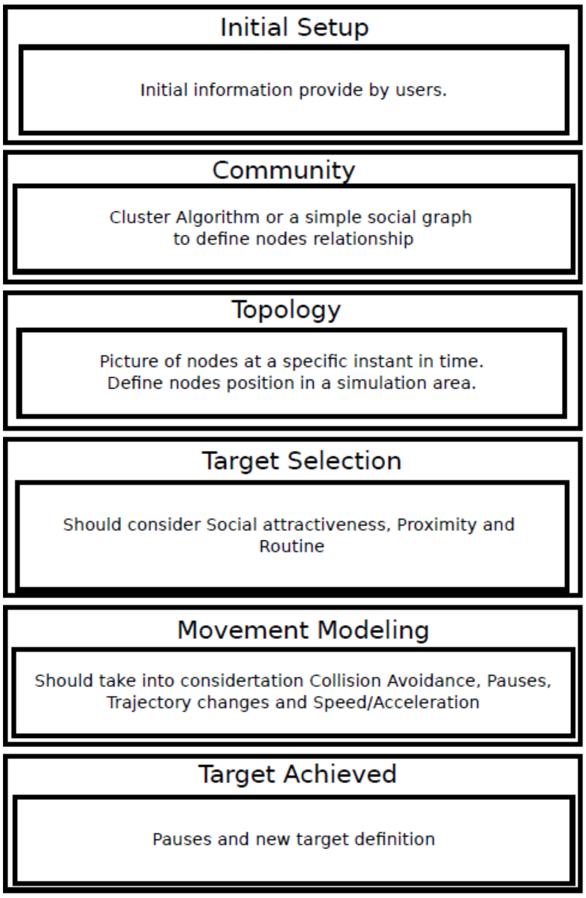

Figure 4.3: Decomposition of a realistic social mobility model.

the next block, and it comprises the utility function, as well as eventual methods required to select a next hop in terms of movement trajectory. The movement modeling block comprises the definition of movement patterns, which include aspects such as; speed and direction of movement, but also comprises stationary times of a node for a specific target.

Chapter 5

Summary of Achievements

As described in section 1.1, the work developed in 2011/2012 relates to activities 2 and 3 of the roadmap proposed on the thesis work plan. We provide a list of achievements next.

- Activity 2: **: Specification/validation phase 1 (July 2011 - June - 2012)**
  - Expected outcome: intermediate report; novel algorithms and/or mechanisms specified (main aspects) and validated (simulations); 1 poster publication; 1 conference publication.
  - Achievements:
    * Intermediate progress report [23].
    * 1 Poster publication - MAPShop 2012 - May 2012.
    * 1 Conference publication - Sep/2011 - ICNP 2011 [24].
    * CMM + Pause Time (i) function [21].
- Activity 3: **Specification/validation phase 2 (June - 2012 - December 2012)**
  - Achievements:
    * 1 Conference Accepted to publication - ISWCS 2012 - Aug/2012 [25].

Chapter 6

Future Work

As next steps we are currently working on the following aspects:

- **Defining blocks for a realistic social mobility model** – Decomposing Social Mobility Models. **Expected deadline: September 2012**.
    - We intend submit a journal paper in *Pervasive and Mobile Computing* - **October 2012**.
- **Using the blocks defined** - Develop a realistic social mobility model. **Expected deadline: November 2012**.
    - We intend submit a paper in *IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks,* WoWMoM 2013 - **December 2012**.
- **Validation, considering the movement modeling** - Do a comparison with existing mobility models and traces. **Expected deadline: November 2012**.
- **Finalize the thesis**. **Expected deadline: July 2013.**

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